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An earthworm cultivation and soil inoculation technique for land restoration

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Abstract

The introduction of selected earthworms into degraded or newly restored land is known to promote soil improvement. However, to collect and introduce the large numbers required for use in land restoration can be costly and time consuming. To overcome these problems, an Earthworm Inoculation Unit (EIU) technique combines cultivation of selected earthworms in soil-based units with an effective method of direct soil introduction. Cultivation of a particular deep-burrowing species was achieved through optimizing temperature, nutrition and population density. At soil inoculation, after 3 months, each 2-l EIU contained all three life stages – adults, cocoons and hatchlings – providing maximum opportunity for successful colonization. Compared with a conventional method of inoculation, the EIU technique gave rise to enhanced survivorship in a compacted clay soil during the first year after inoculation. Earthworm inoculation should become an integral component of sustainable land restoration practice and the EIU technique provides the most effective means of ensuring long-term earthworm colonization, particularly in hostile soil environments.

Keywords: Cultivation; Earthworm; Earthworm Inoculation Unit (EIU); Land restoration; Soil inoculation

1. Introduction

The reclamation of terrestrial sites damaged by human industrial activities should proceed in a number of stages culminating, often after many years (and if desired), in restoration of the original flora and fauna (e.g. Bradshaw, 1983). Many beneficial soil organisms are naturally capable of re-establishing ambient popula-

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tion levels in a short period of time whereas others, due to poor colonization ability, may require direct assistance. Earthworms, renowned for their numerous benefits to soil quality, fall into the latter category. Field experiments with earthworms, particularly in the past 30 years, have shown that deliberate introductions (inoculations) into soils where they are absent lead to marked improvements. Soils reconstructed after mineral extraction, after peat digging or reclaimed from the sea have all benefited from the inoculation of earthworms. This research is summarized by Curry (1988).

Where possible, the original topsoil at an extraction site should be removed and stockpiled, for several years if necessary, and replaced after site restoration (DoE, 1986). However, after stockpiling, the soil recovers its former productive state only slowly (e.g. Scullion et al., 1988) and soil fauna may be devastated by anaerobic conditions or through compaction. Frequently no top soil is available, or is thought to be too expensive, thereby necessitating the use of topsoil substitutes made from mixed subsoil and organic matter (e.g. Marfleet, 1985). Moreover, a feature of restored soils is that they may deteriorate after a short period of time. Although this is often attributed to poor management (e.g. Haigh, 1992), it has been argued that the absence of beneficial soil organisms, principally earthworms, is considerably underestimated (e.g. Luff and Hutson, 1977).

To date, two distinct methods of inoculating earthworms into soils have been developed, each influenced by the availability of earthworm inocula, labour, finances and, more recently, the types of earthworm required. Larger, deep-burrowing, surface-casting earthworms such as *Lumbricus terrestris* L. (the lob worm or night crawler) or *Aporrectodea longa* (Ude) (the black-headed worm) can be obtained from commercial suppliers as the adults are routinely field-collected for use as fishing bait (e.g. Tomlin, 1983). If used for soil improvement schemes, this type of earthworm is normally broadcast on to the soil surface and simply left to burrow down (e.g. Springett, 1985). These species contribute to the creation and maintenance of soil structure through, for example, the incorporation of organic litter into the bulk of the soil and by burrow formation. These and many other activities have beneficial effects on nutrient release, drainage, water-holding capacity and the subsequent growth of vegetation and are discussed in detail by Edwards and Lofty (1977) and Lee (1985).

Smaller, shallow-working species of earthworm such as *Aporrectodea caliginosa* (Savigny) (the grey worm) and *Allolobophora chlorotica* (Savigny) (the green worm) are easily introduced into soils by transplanting worm-rich grass turfs to worm-deficient soils. Transportation of a protective environment with the earthworms (the turf) plus the movement of all life stages (adults, juveniles and cocoons) tend to promote successful colonization (e.g. Stockdill, 1982). Although these species may have a less dramatic effect on soil characteristics than deeper-burrowing species, they may be more capable of colonization during the early stages of soil rehabilitation.

Despite these two methods, it is generally recognised that a dependence on field collection has meant that earthworm inoculation has not been exploited as widely as its potential benefits for land restoration would warrant (Brun et al., 1987).

Curry and Cotton (1983) have suggested that the increased use of earthworm inoculation will depend on the successful development of techniques for mass rearing soil-dwelling earthworm species.

This paper describes the *Earthworm Inoculation Unit* (EIU) technique, developed in order to combine the benefits of earthworm culture with some of the advantages from the "broadcasting" and "turf cutting" methods of inoculation. The EIU technique removes the reliance on field collection of earthworms, as they are bred from a stock source using methods based on data gained from breeding experiments (e.g. Butt et al., 1992; Butt, 1993). The EIU technique also permits the introduction of selected species at controlled rates and promotes sustainable populations particularly under hostile soil conditions. The technique can be divided into two distinct phases: cultivation and soil inoculation. Cultivation involves production of individual units containing soil, feed and earthworms. Within these units a small starter culture of mature individuals, maintained under optimal conditions for a pre-determined period, reproduce at an accelerated rate compared to field earthworms. Inoculation of the intact units into the field, containing all life stages of the selected species, completes the process. Radial migrations from the site of inoculation will then be influenced by soil type and further restoration practices such as irrigation and provision of organic matter. The time scale for complete colonization will depend primarily on the density of EIU introduction, and the nature of the soil into which they are introduced, but would be directed towards a period of 5 to 10 years. This technique is aimed primarily at sites where soil conditions may not favor rapid earthworm colonization and is not viewed as providing an instant high-density population, but rather as a sustainable, "faunal seeding" process.

The experimental work described refers to a trial utilising a deep-burrowing earthworm species (*A. longa*) to illustrate the EIU technique. This species was selected for this particular trial as it is able to enter a resting stage during extremes of drought (Sims and Gerard, 1985) and is also adapted to survival under conditions prone to water inundation, both potential features of clay-capped landfill soils (Dobson and Moffat, 1993). *A. longa* is also one of only a limited number of species that actively cast upon the soil surface and therefore brings about active mixing of soil horizons.

2. Materials and methods

2.1. Cultivation

One hundred Earthworm Inoculation Units (EIUs) were prepared during December 1991. Each consisted of an outer plastic envelope, filled with soil, earthworms and feed. The envelope was formed from a sealable plastic bag (height 30 cm) providing a cylindrical shape when filled (diameter 12 cm). (This design was necessary for ease of insertion during the inoculation stage.) Two litres of sieved topsoil, described by Butt (1991), sterilized to remove potential predators or competitors, was placed within the plastic envelope. This soil had a moisture content of 25–30% of wet soil mass. Approximately 150–200 g of separated cattle solids, a proven feed for earthworms (e.g. Butt et al., 1992), was applied to the soil surface. Four fully reproductive *A. longa* (mean mass 2.5 g) were provided as a starter culture to each EIU. The plastic envelopes were provided with mounted-needle-sized air-holes and then sealed to prevent excessive moisture loss and earthworm escape. The EIUs were stored in darkness within an insulated polythene greenhouse for 12 weeks. During this period sub-soil heating cables maintained EIU temperatures at 18 ± 2°C; temperatures known to promote reproduction of similar earthworm species (Lofs-Holmin, 1983; Butt, 1991).

2.2. Laboratory sampling

After 12 weeks ten randomly selected EIUs were sampled and discarded. The number and mass of earthworms in each unit was recorded and the soil/feed mixture was searched for cocoons, by wet-sieving through a mesh series; sizes 6.7, 3.4, and 2.0 mm. Cocoon number was recorded and each was incubated at 15°C to determine viability.

2.3. Inoculation

The remaining, unsampled EIUs were transported to a partially restored landfill site at Calvert, Buckinghamshire (nat. grid ref. SP692238) for soil inoculation, as part of a larger study. The surface soil at this site is a 1-m agricultural cap of compacted clay (details in Table 1). This lies above 1 m of highly engineered Oxford clay covering approximately 30 m of household refuse. The agricultural cap was sown with a perennial rye grass mixture (DoE, 1986), 2 years before earthworm inoculation. A survey of the site by the authors prior to inoculation, using a variety of extraction methods (Lee, 1985), produced no earthworms.

Soil inoculation was achieved by drilling holes, approximately 0.15 m deep, using a tractor-driven soil auger, at predetermined locations on a grid system at 5- or 10-m intervals. Each EIU was then inoculated into the soil manually; the plastic envelope was split and removed from below, allowing the contents to be lowered into the soil. The integrity of the units was maintained and minimal disturbance to the worms and their micro-environment achieved. The soil/feed matrix remained

Table 1
Selected characteristics of the restored agricultural cap, above landfill, into which Earthworm Inoculation Units were introduced

Soil type	Bulk density (g/cm^3)	pH	Organic content (%) (at 0.1 m depth)	Moisture content (%) (at 0.1 m depth)	Total (%) carbon	Total (%) nitrogen	Other information
Clay	1.4	7.6	3.9	27	2.1	0.08	Methane actively vented

Methods of analysis described in Anonymous (1986).

intact, ensuring that the position of deposited cocoons, relative to the soil surface, remained constant.

A further 160 mature, healthy, field-collected *A. longa* (mean mass 2.2 g) were also inoculated into the clay cap in batches of 4 ($n = 40$) by the broadcast method. Each inoculation site, EIU or otherwise was supplied with a surface dressing of farmyard manure and permanently marked. A 2-ha area, which included the inoculation grid, was irrigated with treated landfill leachate as required during the summer months.

2.4. Field sampling

After 10 months (February 1993) a visual count of surface casting by *A. longa* was made around the points of EIU and broadcast inoculation, as described by Evans and Guild (1947). The position of casts relative to the point of inoculation was recorded. In a number of instances ($n = 25$) the soil beneath the casting was dug out and burrow depth, plus the number of earthworms present recorded.

3. Results

3.1. Cultivation

The mean number of *A. longa* produced in the EIUs was 29.0 ± 3.9 (maximum value 52) at a rate of 2.4 cocoons per worm per month (Table 2). In all EIUs sampled the full complement of starter culture adults was present. However, 63% of these earthworms had entered a senescent state and were no longer in reproductive condition. Of the 250 cocoons incubated at 15°C, 167 hatched successfully (67%). All cocoons produced a single hatchling.

3.2. Field sampling

One hundred and twenty-seven clearly defined casts were located around the EIUs. Casts were found over 2 m from some points of inoculation although the mean distance recorded was 0.7 m (Fig. 1). Mean burrow depth below casts was 0.18 m (maximum 0.28 m). On excavation of casts, a single mature *A. longa* was recovered on all but three occasions, when two mature earthworms were located.

Table 2
Cultivation phase data from 2-l Earthworm Inoculation Units (EIUs) after 12 weeks at a temperature of 15–20°C

Earthworm species	No. of adults in starter culture	Mean mass (g)	Mean reproductive output		Total earthworms per EIU at inoculation
			Cocoons	Hatchlings	
A. longa (black-headed worm)	4	2.5	25	4	33

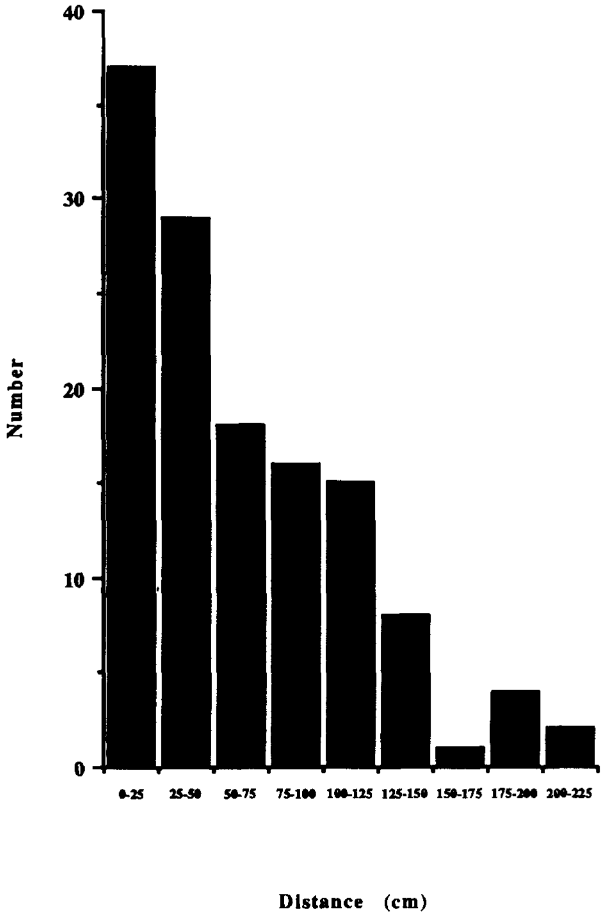

Fig. 1. Distribution of movements through a compacted clay soil by introduced *A. longa* after a period of 10 months (from surface cast observation) ($n = 130$, mean = 0.7 m).

These earthworms (mean mass 2.7 g) were all in reproductive condition. Zero casting was found around the sites of inoculation using the broadcast method. Extensive digging in this area failed to produce a single earthworm.

4. Discussion

4.1. Cultivation

An 8-fold increase in *A. longa* numbers was recorded over 12 weeks. This compares with a doubling over a similar time period from field-equivalent data for the same species (Evans and Guild, 1948). Reproduction rates during the EIU trial exceeded those found during controlled, pot-scale laboratory experiments for this species (Butt, 1993) whilst cocoon hatchability figures were similar. An overall success rate of 71% was obtained when combined with those cocoons which had already hatched within the EIUs at time of sampling, which is not significantly different from the value of 70% obtained by Butt (1993).

The accelerated reproductive rate can be accounted for by provision of optimal environmental conditions and no disturbance during the 12-week cultivation period. A lengthier cultivation phase might theoretically lead to further cocoon production but would involve a need to provide extra feed and the total starter culture would almost certainly become reproductively fatigued (Evans and Guild, 1948; Butt et al., 1992). Overall earthworm biological performance was excellent using the polythene-bound EIUs, the total number of *A. longa* (in all life stages) inoculated into the clay cap within ninety 2-l EIUs was 2970. One major advantage of this type of cultivation is the unit-based system. Total loss of earthworms through pathogenic attack is unlikely, in contrast to large "worm-bed" systems, used for brandling (*Eisenia fetida*) production of the type described, for example, by Edwards (1988).

4.2. Survivorship and movement

Although the amount of earthworm casting may vary with temperature and soil moisture (e.g. Lee, 1985) the number of individual casts on the surface is a good indication of the number of *A. longa* present in a single-species trial. Therefore the proportion of earthworms surviving 10 months after EIU inoculation and able to produce surface casts, was approximately 35%. This assumes that all adults inoculated into the landfill cap were casting. It does not account for earthworms which were not apparently casting at this time, as located during burrow measurement, and more importantly juvenile earthworms which may not produce surface castings. The latter were not specifically searched for, as digging was the only option available. (Extraction using a chemical irritant was undesired.)

Recorded earthworm movement away from the point of inoculation, at 0.7 m per year, is well below the figure of 4–6 m per year recorded by van Rhee (1969) in reclaimed Dutch polders. However, the latter result, often cited as an expected figure for earthworm migration, does not relate specifically to deep-burrowing earthworms such as *A. longa*, but includes the movements of smaller species such as *A. caliginosa*. Also the soil conditions in reclaimed polders are much more hospitable than those of a reclaimed landfill site. Weidemann et al. (1982) cite figures from Schriefer (1979) suggesting that natural colonization of reclaimed landfill cover is less than 4 m per year and this is exclusively by species with horizontal, near-surface burrows.

The failure to locate the inoculum of *A. longa* broadcast on to the cap surface, suggests that this type of inoculation was unable to ensure earthworm survival and population development in the hostile conditions of the compacted clay cap, although this method has proven successful with this species in fertile New Zealand pasture (Springett, 1985). It is possible that the broadcast inocula may have performed long-range over-surface migrations, as recorded for *L. terrestris* in pasture (Mather and Christensen, 1992), but the fact that earthworms introduced within EIUs are still within 3 m of inoculation sites tends not to support this. It would appear that the broadcast inoculum have all perished while acceptable results have been achieved using the EIU technique. It is contended that the EIU technique is the only viable method for population establishment under these soil conditions, but sampling in subsequent years will be required to determine further rate of spread, population development and long-term sustainability.

In general, earthworms should not be regarded as a panacea in soil restoration. If deemed necessary, timing of their introduction needs to coincide with, for example, the establishment of site drainage and preferably when suitable food is available and should then only occur in the most appropriate way. Unlike other beneficial soil fauna, earthworms often require assistance at reaching reclaimed areas as sites may be completely surrounded by drainage ditches, for example, which present barriers to colonization.

The EIU technique allows successful earthworm inoculation under very inhospitable soil conditions. All three life stages, mature worms, juveniles and cocoons, provide founder earthworm populations with an enhanced probability of long-term survival. This technique provides a means of achieving sustainable earthworm colonization, with potential benefits in land restoration.

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